Investigating low energy nuclear reactions in glow discharge plasmas

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Abstract

The plasma glow discharge experiment aims to identify the **interaction cross section of low energy fusion reactions through simulation and experiment.** The plasma is formed in a chamber of Deuterium gas, held between 0.1 and 0.5 Torr, with a central cathode wire and a surrounding anode cage. **An electric potential (3kV-10kV)** is periodically applied between the electrodes. This ionizes the plasma further. Deuterium atoms are accelerated towards the cathode. The incident Deuterium ions fuse with Deuterons embedded in the cathode. **A liquid scintillator captures the fast neutron products.** Pulse discrimination of the photoelectric flux signals is used to identify particle species. There are two distinct bands of data that correspond to gamma signals and fast neutron signals in the pulse discrimination results. This allows for estimations of the number of fast neutron products from fusion reactions at the cathode. In addition, Warp plasma simulations are being developed to confirm the results of VORPAL simulations for the energy distributions of incident ions. The Warp plasma simulation value for the plasma sheath thickness is consistent with VORPAL's **sheath thickness result of ~ 7mm**, when using the equilibrium plasma density supplied by VORPAL. To achieve a full comparison of the two simulations more collisions that occur within the sheath need to be inputted into the Warp simulation. The pulse discrimination analysis and plasma simulations have made progress towards determining two of the quantities necessary for identifying the interaction cross section.

Plasma Formation and Monitoring

Vacuum chamber filled with neutral deuterium gas.

- Applied potential: **3kV – 10kV**
- Applied at intervals of **20ms**
- Duration: **20µs**

Deuterium fusion collisions at the cathode:

- D + D → T + P (50%)
- **D + D → ^{3}He + n** (50%)

EJ309 liquid scintillator used for fast neutron detection
Photomultiplier tube (PMT) converts/amplifies photon flux
Current converted to voltage and stored using the Picoscope

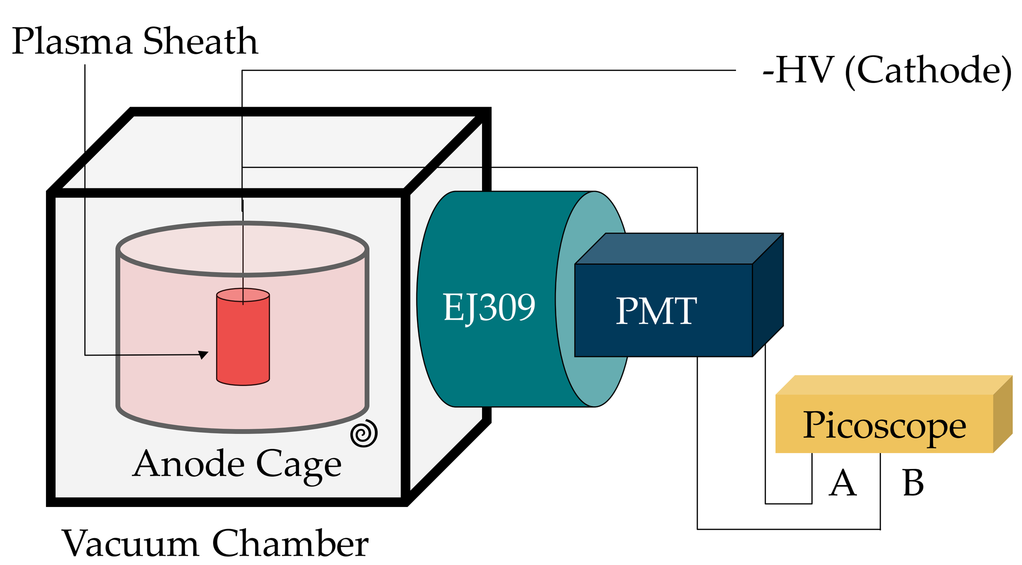

Figure 1: Experimental set-up for the plasma glow discharge formation and neutron product detection.

Data is stored by the Picoscope only when ChA is triggered and the signal from ChA coincides with the applied voltage monitored by ChB.
This method **increased the signal to noise ratio by a factor of 1000** and the signal rate reduced from kHz to Hz.
Data acquisition:

- Triggering on voltage levels below 0.1V
- Data stored only when the potential difference is activated

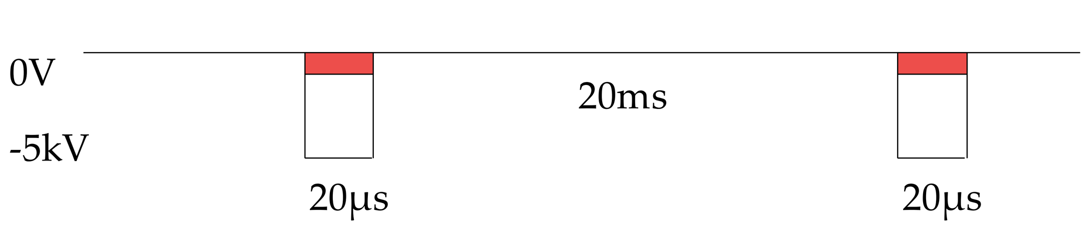

Figure 2: The high voltage is applied to the cathode wire at a frequency of 50Hz with a duration of 20µs.

Fusion Reaction Neutron Product Counting

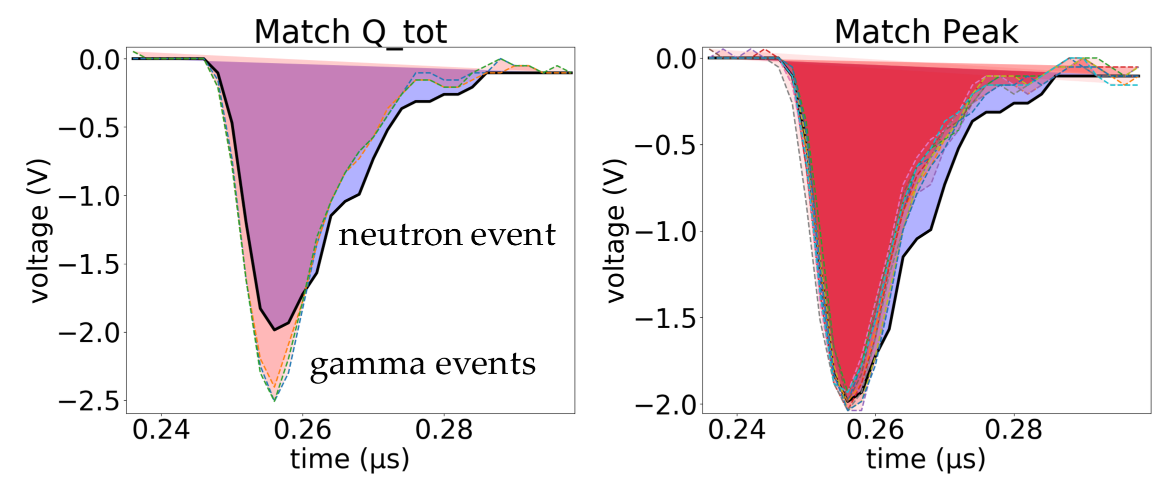

Figure 3: Voltage vs time data of a neutron event overlaid by 10 detected gamma events with the same total charge value/ same peak voltage.

Organic liquid scintillators yield two types of light

- A fast component and a slow component
- the **relative intensities** of the fast and slow components **depend on** dE/dr
  - Thus the **shape** of the pulse **depends on the ionizing particle**

Thus pulse discrimination can be used to determine particle type

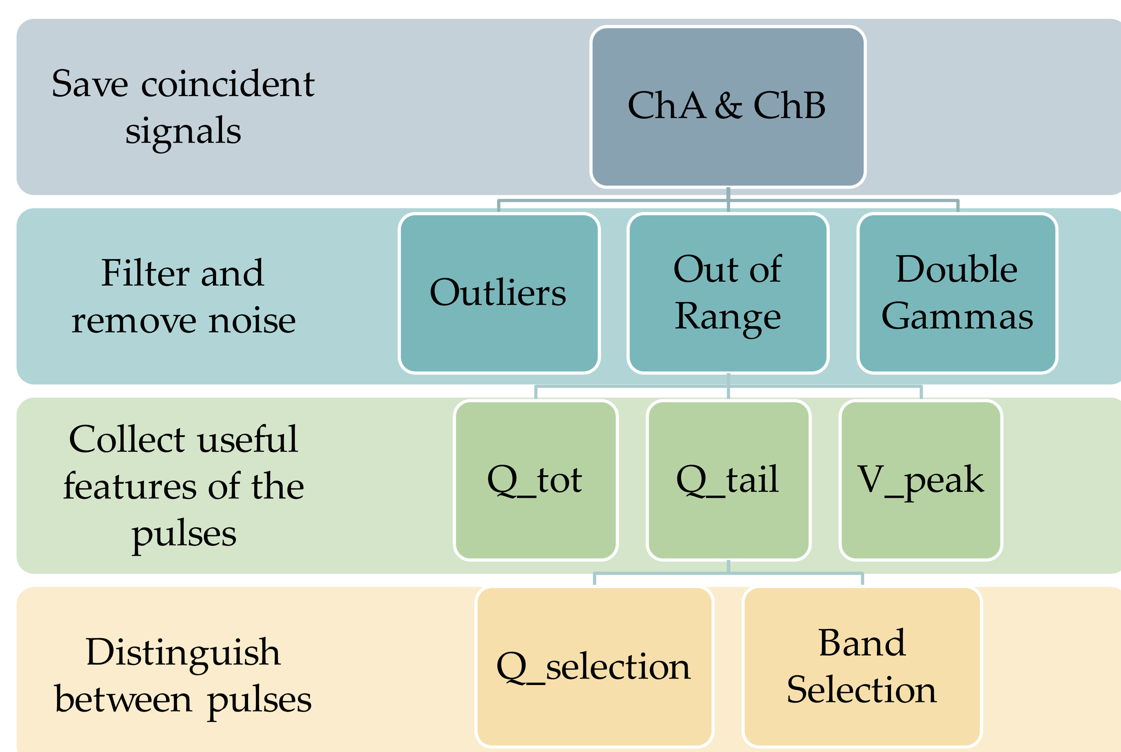

Figure 4: Python data analysis of Picoscope data flow chart.

Integral under the voltage vs time of a pulse (Figure 3) is the total charge.

The tail charge is the integral of the pulse of a particular window in nanoseconds after the peak of the pulse occurs.

- The ratio of total charge to tail charge is useful for distinguishing between gamma and neutron events
- Two band are formed, the steep band is a collection of suspected gamma events and the second, shallow band, is a collection of suspected neutrons
- The orange stain of on the plots below is defined by a range of the full width half max of the pulses that is suspected to correspond to neutrons events

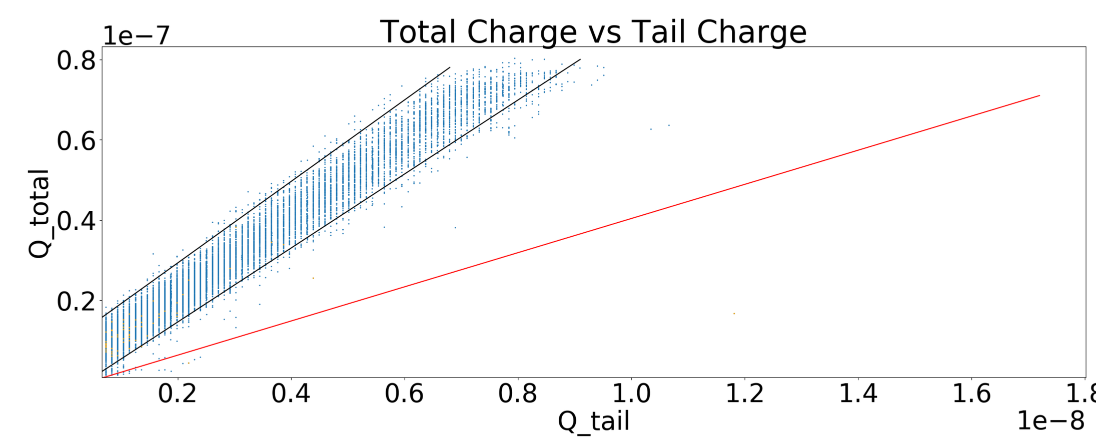

Figure 5: Background run with a bias on the photomultiplier tube of 1700V. Used for determining the background levels of gammas and neutrons.

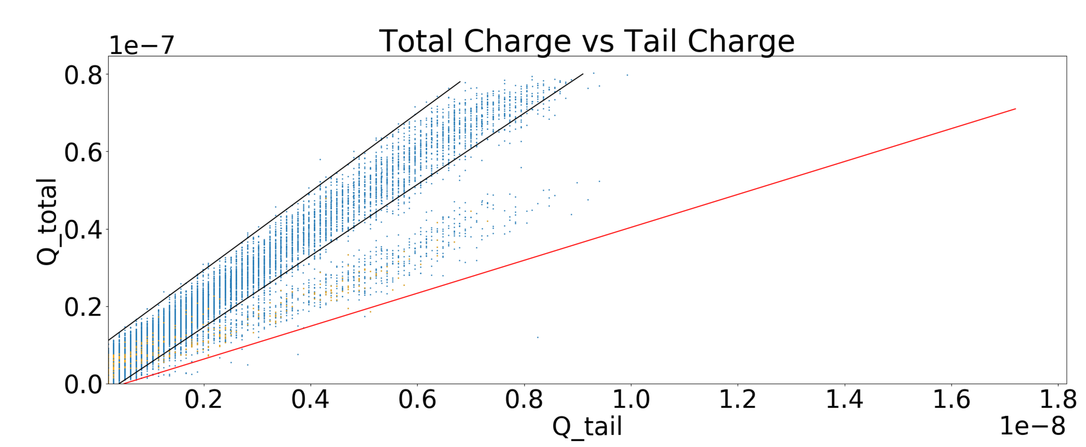

Figure 6: Neutral gas pressure of 0.5 Torr, -5kV applied voltage to the cathode, and 1700V bias on the photomultiplier tube.

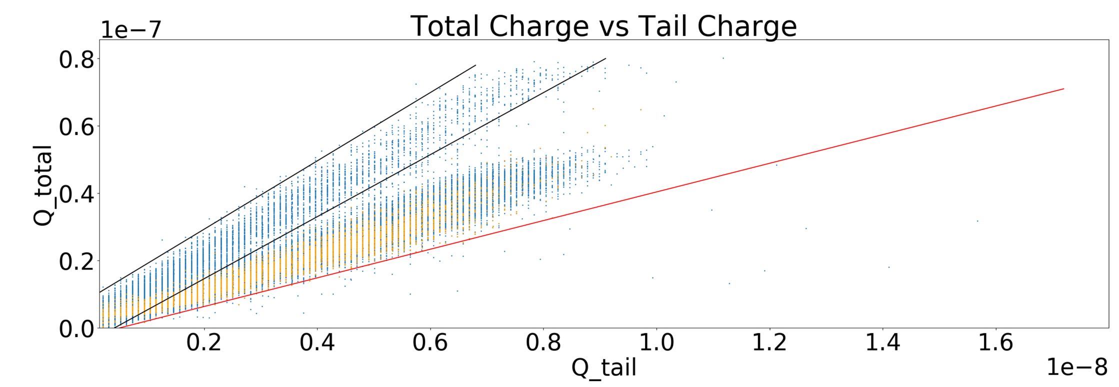

Figure 7: Neutral gas pressure of 0.5 Torr, -10kV applied voltage to the cathode, and 1700V bias on the photomultiplier tube.

Pulse Shape Discrimination Results:

- Developed a program to acquire data and reduce the signal to noise ratio.
- Observed signals from suspected neutron events. Identified two distinct bands.
- Developed a foundation for calculating the neutron detection rate using EJ309 in line with the goal of distinguishing the fusion products from the background
- Monitored the change in neutron detection rate as a function of voltage applied to the cathode and thus the energy distribution of ions at the cathode.

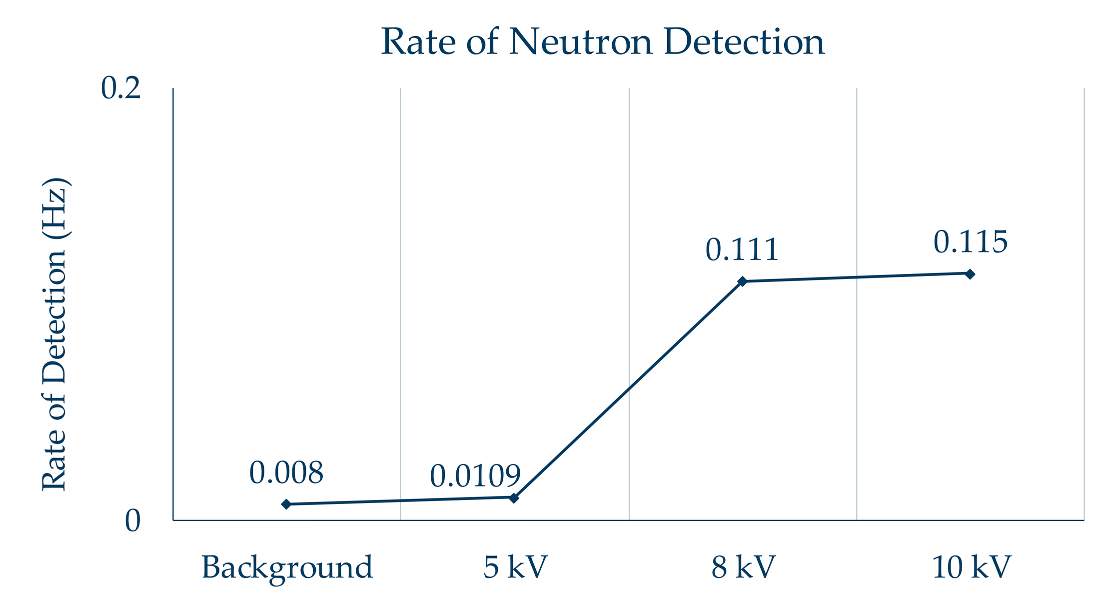

Figure 8: The preliminary results of neutron rate at background and different applied potentials after filtering through the data.

Simulation of the Energy Distribution of Deuterons at the Cathode

Essentially a 1D simulation of a plasma in a box using Warp

- Warp is an open-source particle-in-cell Python package
- Initial density of 10^{17} per cc as previously simulated
- **Inserted reactions key to sheath dynamics**

Purpose:

- Identify sheath thickness
  - Determines **particle path length,** therefore number of collisions
- Ion energies at the cathode
  - Dependent of sheath thickness, plasma density, ect.
- Head to head comparison with existing commercial simulation (VORPAL)

Inserted Collisions:
($\sigma \sim 10^{-17} - \sigma \sim 10^{-15}$ *per* cm^2)

- Elastic Collisions: $e + H_2 \rightarrow e + H_2$
- H3+ Formation: $H_2^+ + H_2 \rightarrow H_3^+ + H$
- Ionization Collisions: $e + H^2 \rightarrow 2e + H^2$
- Charge Exchange: $H_2^+ + H_2 \rightarrow H_2 + H_2^+$

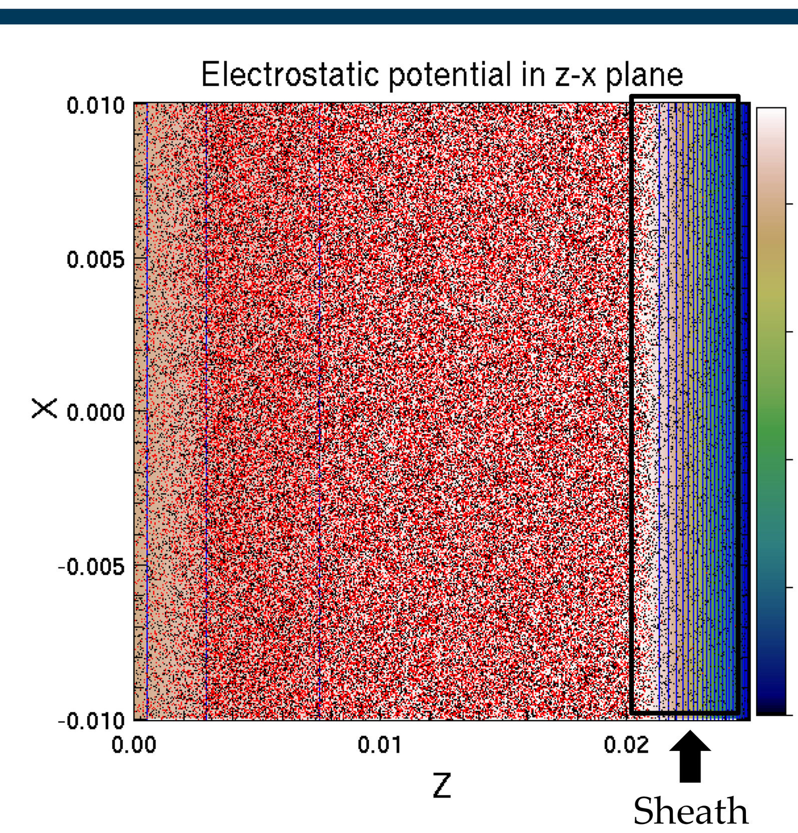

Figure 9: Map of the potential of the plasma modeled through simulations during the 20µs applied potential pulse.

The full potential difference between the anode and cathode is distributed across the plasma sheath.

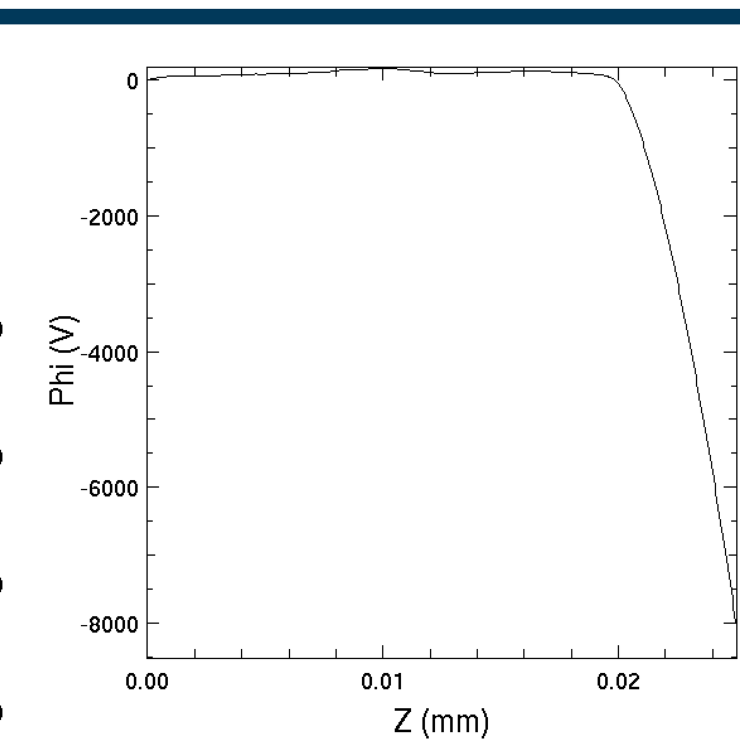

Figure 10: Model of the potential of the plasma as a function of position.

Simulation Progress/ Results

- **~7mm sheath** thickness
  - Consistent with VORPAL's prediction
- **smeared distribution of ion energies,**
  - supports the prediction that the sheath is highly collisional at the plasma pressure of 10^17 per m^3

Future Steps

- Refine the methods of removing coincident gamma-gamma and gamma-neutron signals
- Use machine learning to identify and count neutron pulses
- Increase the sensitivity of the measurements to find neutron count at lower pressures
- Integrate more challenging collisions into the Warp simulation
- Explore fluid simulations as a less computationally expensive method of simulating the bulk plasma
- Use a new edition of the Picoscope to periodically collect background data during the 20ms when the high voltage is not applied

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